Coherence of Sound using Navy Sonars

John Spiesberger
Scientific Innovations, Inc.
6 Derring Dale Rd., Radnor, PA 19087
phone: (610) 293-0834 fax: (610) 293-0834 email: johnsr@sas.upenn.edu

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LONG-TERM GOALS

The long-term goal is to understand and predict temporal and spatial coherence of broadband sound in the ocean at low frequencies.

OBJECTIVES

We will compare with predictions temporal and spatial coherence of broadband acoustic signals at basin-scales. Degradation of coherence will be modeled using spectra of internal waves in the ocean.

APPROACH

Data will be collected from a variety of Navy sonars. Traditional means to process signals will be utilized including beamforming, coherent averaging (when dealing with periodic signals), correcting for Doppler shifts (when dealing with mobile sonars), and matched filtering (when a replica with the emitted waveform is available). Data will be interpreted using rays and the sound speed insensitive parabolic approximation (Tappert *et al.* 1995) . Acoustic models will be used in conjunction with oceanographic models that contain the best available digital data sets for bathymetry, sound speed fields that vary with range and depth, and internal waves. Spatial coherence will be modeled using the sound speed insensitive parabolic approximation and spectra of internal waves.

Another goal is to investigate effects of internal waves in limiting horizontal coherence of sound at low frequencies and long distances (<200Hz and greater than 1000 km). In particular, we want to estimate if effects of horizontal refraction, diffraction, or scattering are significant.

WORK COMPLETED

Data have been collected and processed from several types of sonars at basin-scales in the Pacific ocean. Acoustic models have been developed that incorporate realistic bathymetry, sound speed fields that change with geographic location, and time dependent fluctuations of internal waves obeying a linear dispersion relation. Comparisons with some data are complete.

Using Monte-Carlo methods, we compared effects of horizontal scattering of sound up to 150 Hz and 4000 km in the presence of internal waves.

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RESULTS

A 3683 km section in the Pacific was studied using sounds from a bottom-mounted source at Kauai (75 Hz, 0.03 s resolution) and a towed array in the Gulf of Alaska (Fig. 1). The transmitted signal consisted of 44 consecutive 27.28 s periods of a M-sequence lasting 20 min. Data from the receiver were beamformed and Doppler corrected to yield the largest signal-to-noise ratio. This processed signal yielded many acoustic arrivals over a 12-s duration. This 12-s was subdivided into 380 windows of 0.03 s each. Starting from the first of 42 periods, the signal-to-noise ratio was computed for each window as a function of the number of windows coherently averaged with the first. Coherence time, T, for each window was calculated using T=N*27.28 s where N is the window yielding the largest signal-to-noise ratio (N=1,2,3,...,42). Fig. 2 (top) shows the histogram of coherence time from these data. The most likely is 20 min. This is the maximum allowed with a 20-min transmission. It is possible that some multipath have coherence times exceeding 20 min, but this cannot be measured with these data.

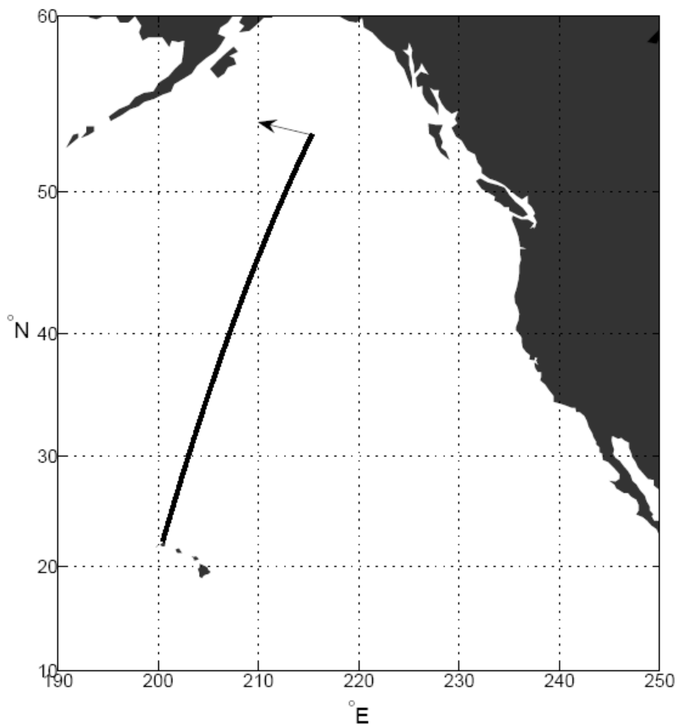

Fig. 1. 3683 km section between acoustic source at Kauai and array towed in shown direction.

A model is used to predict, without any tuning to data, the histogram of coherence time from the data. The model uses digital data bases for bathymetry and the climatological background of temperature, salinity, and depth along the section. Values of temperature and salinity are converted to sound speed with an algorithm. To this, we add temporal fluctuations due to internal waves at 4-min intervals using the linear dispersion relation obeying a standard spectrum. An approximate solution for the acoustic impulse response is computed using the sound-speed insensitive parabolic equation. The histogram of modeled coherence time looks very much like the data (Fig. 2, bottom). Details of this comparison are found elsewhere (Spiesberger, 2008a).

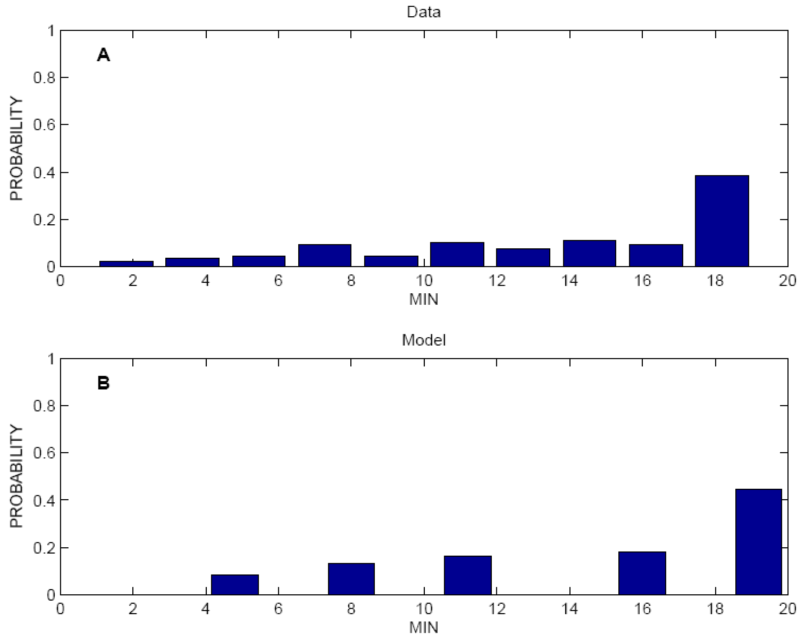

Fig. 2. Histograms of measured and modeled coherence time for section in Fig. 1.

We found negligible effects from horizontal refraction, diffraction, and scattering at 75 Hz and 4000 km in the presence of a standard spectrum of internal waves (Spiesberger 2008b, Fig. 3). The result is based on comparison of numerical solutions of the 3-D and 2-D linear acoustic wave equations employing the sound speed insensitive parabolic approximation (Tappert et al., 1995). The 2-D solution takes vertical slices through the simulated ocean only, and neglects effects from horizontal variations in the model. Similar results are found at 150 Hz (Spiesberger, 2008c). Our results imply that the frequently employed 2-D approximation is valid up to at least 150 Hz and 4000 km. This is good news since 3-D solutions require lengthy computations.

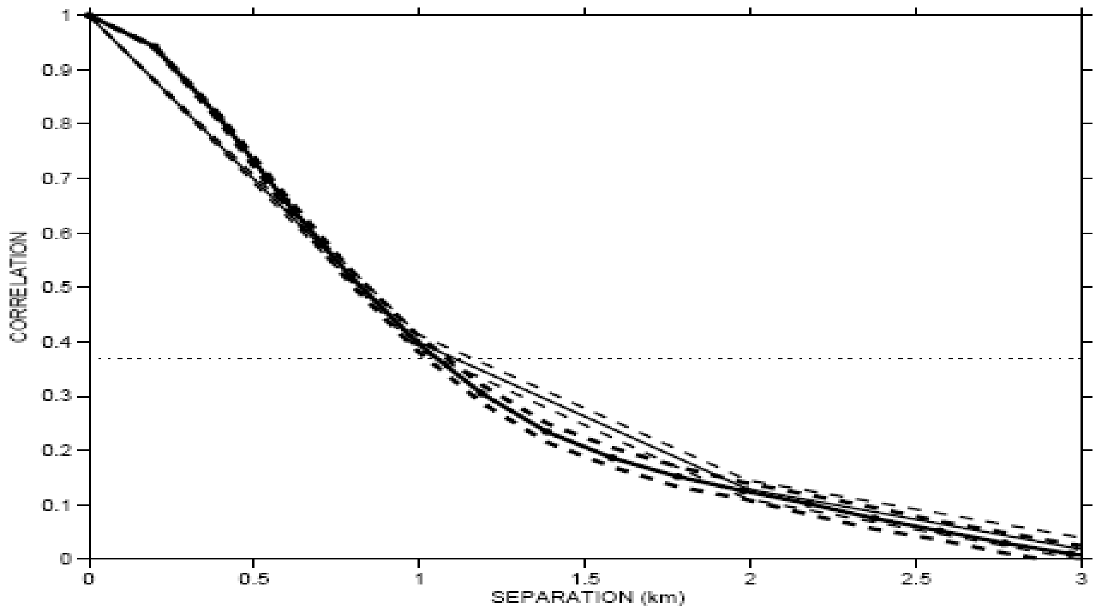

Fig. 3. 95% confidence limits for horizontal correlation at 75 Hz and 4000 km distance from source for uncoupled azimuth (dark lines) and coupled azimuth (light lines) solutions to the sound speed insensitive parabolic approximation. The dotted line is a value of 1/e.

IMPACT/APPLICATIONS

Reliable models for acoustical coherence are useful for experimental design and designing and operating acoustic surveillance and communication systems. Understanding when the 2-D approximation of the 3-D acoustic wave equation is valid has applications for surveillance and communication systems as well as experimental design and scattering theory.

RELATED PROJECTS

Drs. Voronovitch, Ostashev, and Godin at NOAA in Boulder, CO., are developing theories for the three-dimensional scattering of sound in the sea. Morozov and Colosi are considering numerically efficient means to compute temporal coherence in the presence of internal waves. Other scientists are computing effects of internal waves on the temporal coherence of sound from models and data.

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PUBLICATIONS

Spiesberger, J.L., Comparison of measured and modeled temporal coherence of sound near 75 Hz and 3683 km in the Pacific ocean, J. Acoust. Soc. Am., 2008a [in press, refereed].

Spiesberger, J.L., Comparison of two and three spatial dimensional solutions of the wave equation at ocean-basin scales in the presence of internal waves, J. Computational Acoustics, 15, 319-322, 2008b [published, refereed].

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